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DECLARATION

I, Shinichi Usui, a Japanese Patent Attorney registered No. 9694, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 7-066991 filed on February 28, 1995 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

signed this 25th day of January, 2000

Shinichi Usui

PATENT OFFICE
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This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Application Number: Japanese Patent Application No. 7-066991

Applicant(s): CANON KABUSHIKI KAISHA

March 29, 1996

Commissioner, Patent Office YUJI KIYOKAWA (Seal)

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[Name of the Document] Specification

[Title of the Invention] Scanning Optical Apparatus and Multibeam Scanning Optical Apparatus

[What is claimed is:]

[Claim 1] A scanning optical apparatus in which a beam of light emitted from a light source means is imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element, and said beam of light deflected by said deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element, so as to scan said surface to be scanned, characterized in that:

said third optical element comprises a single lens, the both opposite lens surfaces of said single lens comprise a toric surface of an aspherical surface shape in the main scanning plane, and the curvature of said opposite lens surfaces in the sub scanning plane is continuously varied from the on-axis toward the off-axis in an effective portion of the lens, thereby preventing a change of the F number in the sub scanning direction from being caused by the image height of the beam of light incident on said surface to be scanned.

[Claim 2] A scanning optical apparatus according to Claim 1, wherein said light source means has a plurality of light source units capable of being independently modulated.

[Claim 3] A scanning optical apparatus according to Claim 1 or 2, wherein when the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of said third optical element in the sub scanning direction (the difference in the direction of the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, the following condition is satisfied:

$$xm \leq dx \leq xu,$$

where

[Numerical formula 1]

$$dx = \frac{Ipri \cdot Epri(\cos\theta img - \cos\theta por)}{Ipri \cdot \cos\theta por + Epri \cdot \cos\theta img}$$

Ipri is the distance from the deflecting surface of the deflecting element in the on-axis beam to the front side principal plane in the sub scanning direction;

Epri is the distance from the rear side principal plane in the sub scanning direction in the on-axis beam to the surface to the scanned;

θpor is the angle formed in the main scanning plane by the most off-axis beam deflected by the deflecting element with respect to the optical axis;

θimg is the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis.

[Claim 4] A scanning optical apparatus according to Claim 1 or 2, wherein the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting said third optical element in the sub scanning plane is reversed from the on-axis toward the off-axis.

[Claim 5] A scanning optical apparatus according to Claim 1 or 2, wherein said third optical element is made by plastic molding.

[Claim 6] A scanning optical apparatus according to Claim 1 or 2, wherein said third optical element is made by glass molding.

[Detailed description of the Invention]

[0001]

[Field of the Industrial Utilization]

This invention relates to a scanning optical apparatus, and particularly to a scanning optical apparatus suitable for use, for example, in an apparatus such as a laser beam printer (LBP) or a digital copying apparatus having the electrophotographic process adapted to deflect and reflect a beam of light optically modulated and emitted from light source means by a light deflector (deflecting element) comprising a rotatable polygon mirror or the like, thereafter optically scan a surface to be scanned through an imaging optical system having the fθ characteristic (fθ lens) and record image information.

[0002]

[Prior Art]

Heretofore, in the scanning optically apparatus of a laser beam printer or the like, a beam of light optically modulated and emerging from light source means in conformity with an image signal has been periodically deflected by a light deflector comprising, for example, a rotatable polygon mirror and has been converged into a spot-like shape on the surface of a

photosensitive recording medium (photosensitive drum) having the fθ characteristic, and that surface has been optically scanned to thereby effect image recording.

[0003]

Figure 16 of the accompanying drawings is a schematic view of the essential portions of a scanning optical apparatus according to the prior art.

[0004]

In Figure 16, a divergent beam of light emitted from light source means 61 is made into a substantially parallel beam of light by a collimator lens 62, and the beam of light (the quantity of light) is limited by a stop 63 and enters a cylindrical lens 64 having predetermined refractive power only in a sub scanning direction. Of the parallel beam of light having entered the cylindrical lens 64, that part in a main scanning section intactly emerges in the state of a parallel beam of light. Also, that part in a sub scanning section converges and is imaged as a substantially linear image on the deflecting surface (reflecting surface) 65a of a light deflector 65 comprising a rotatable polygon mirror.

[0005]

The beam of light deflected and reflected by the deflecting surface 65a of the light deflector 65 is

directed onto the surface of a photosensitive drum 68 as a surface to be scanned through an imaging optical system (fθ lens) 66 having the fθ characteristic, and the light deflector 65 is rotated in the direction of arrow A to thereby optically scan the surface of the photosensitive drum 68 and effect the recording of image information.

[0006]

[Problems to be solved by the Invention]

To effect the highly accurate recording of image information in a scanning optical apparatus of this kind, it is necessary that curvature of image field be well corrected over the entire area of a surface to be scanned and a spot diameter be uniform and that the angle and image height of the incident light have distortion (fθ characteristic) in which they are in a proportional relation. A scanning optical apparatus satisfying such optical characteristics or the correcting optical system (fθ lens) thereof has heretofore been variously proposed.

[0007]

On the other hand, with the tendency of laser beam printers, digital copying apparatuses, etc. toward compactness and lower cost, similar things are required of the scanning optical apparatus.

[0008]

As an apparatus which makes these requirements compatible, a scanning optical apparatus in which the fθ lens is comprised of a single lens is variously proposed, for example, in Japanese Patent Publication No. 61-48684, Japanese Laid-Open Patent Application No. 63-157122, Japanese Laid-Open Patent Application No. 4-104213, Japanese Laid-Open Patent Application No. 4-50908, etc.

[0009]

Of these publications, in Japanese Patent Publication No. 61-48684 and Japanese Laid-Open Patent Application No. 63-157122, a concave single lens as on fθ lens is used on the light deflector side to converge a parallel beam of light from a collimator lens on the surface of a recording medium. Also, in Japanese Laid-Open Patent Application No. 4-104213, as fθ lenses, a concave single lens and a toroidal-surfaced single lens are used on the light deflector side and the image plane side, respectively, to make a beam of light converted into convergent light by a collimator lens enter the fθ lenses. Also, in Japanese Laid-Open Patent Application No. 4-50908, a single lens introducing a high-order aspherical surface into a lens surface is used as an fθ lens to make a beam of light

converted into convergent light by a collimator lens enter the fθ lens.

[0010]

However, in the scanning optical apparatuses according to the prior art described above, according to Japanese Patent Publication No. 61-48684, curvature of image field in the sub scanning direction remains and a parallel beam of light is imaged on the surface to be scanned, and this has led to the problem that the distance from the fθ lens to the surface to the scanned becomes a focal length f and is long and it is difficult to construct a compact scanning optical apparatus. In Japanese Laid-Open Patent Application No. 63-157122, the thickness of the fθ lens is great, and this has led to the problem that manufacture by molding is difficult and this makes a factor of increased cost. Japanese Laid-Open Patent Application No. 4-104213 has suffered from the problem that distortion remains. In Japanese Laid-Open Patent Application No. 4-50908, an fθ lens having a high-order aspherical surface is used and aberrations are corrected well, but there has been the problem that jitter of a period corresponding to the number of polygon surfaces occurs due to the mounting error of a polygon mirror which is a light deflector.

[0011]

Further, problems common to these fθ lenses each comprised of a single lens has included the problem that due to the non-uniformity of the lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned, the spot diameter in the sub scanning direction changes depending on image height.

[0012]

(A) and (B) of Figure 17 of the accompanying drawings are cross-sectional views of the essential portions of a single beam scanning optical apparatus in the main scanning direction and the sub scanning direction, respectively, and show changes in the spot diameter in the sub scanning direction due to image height. In these views, the same elements as the elements shown in Figure 16 are given the same reference numerals.

[0013]

Usually, in a plane inclination correcting optical system, it is necessary to bring the deflecting surface of a light deflector and a surface to be scanned into an optically conjugate relation (imaging relation) in order to optically correct the plane inclination of the deflecting surface. Accordingly, in an fθ lens having

a predetermined lens shape in the main scanning section as in the aforedescribed examples of the prior art, lateral magnification is high on the axis (on-axis beam 21) as indicated at (1) in (B) of Figure 17, and lateral magnification becomes low off the axis (most off-axis beam 22) as indicated at (2) in (B) of Figure 17 (there is also a case where this becomes converse depending on the lens shape in the main scanning section).

[0014]

Thus, irregularity occurs to the lateral magnification in the sub scanning direction depending on the lens shape of the fθ lens in the main scanning plane thereof and a change in the spot diameter in the sub scanning direction due to image height occurs.

The above-described non-uniformity of the lateral magnification in the sub scanning direction makes the curve of the scanning line when the position of a light source (light source unit) is off the optical axis in Z direction indicated in Figure 17 and therefore, an optical system such as a multibeam scanning optical system (multibeam scanning optical apparatus) which scans a surface to be scanned at a time by the use of a plurality of beams of light off the optical axis has suffered from the problem that the scanning line bends

on the surface to be scanned and as a result, the deterioration of image quality due to pitch irregularity occurs.

[0015]

It is an object of the present invention to provide a compact scanning optical apparatus suitable for highly accurate printing in which when a beam of light converted by a collimator lens is to be imaged on a surface to be scanned by an fθ lens through a light deflector, the lens shape (the main scanning plane shape) of the fθ lens in the main scanning plane thereof is optimized to thereby correct curvature of image field, distortion, etc. and the non-uniformity of lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned is eliminated by only the lens shape (the sub scanning plane shape) in the sub scanning plane, independently of the lens shape in the main scanning plane, whereby any change in F number (F No.) in the sub scanning direction due to image height, i.e., any change in spot diameter, can be suppressed.

[0016]

It is another object of the present invention to provide a compact scanning optical apparatus suitable, for example, for multibeam scanning in which a a beam

of light from the light source (light source unit) which is off the optical axis can also be scanned highly accurately without the curve of the scanning line occurring.

[0017]

[Means for solving the Problems]

The scanning optical apparatus of the present invention is

a scanning optical apparatus in which a beam of light emitted from light source means is imaged into a linear shape long in the main scanning direction on the deflecting surface of a deflecting element through a first optical element and a second optical element and the beam of light deflected by the deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element to thereby scan the surface to be scanned, characterized in that the third optical element comprise a single lens, the opposite lens surfaces of the single lens both comprise a tori surface of an aspherical shape in the main scanning plane, and the curvature thereof in the sub scanning section is continuously varied from the on-axis toward the off-axis in the effective portion of the lens to thereby suppress any change of F number in the sub scanning direction due to the image height of

the beam of light incident on the surface to be scanned.

[0018]

Particularly, it is characterized in

that the light source means has a plurality of light source means has a plurality of light source units capable of being independently modulated,

that when the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of the third optical element in the sub scanning direction (the difference in the direction of the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, the following condition xm≤dx≤xu, is satisfied:

where

[0019]

[Numerical Formula 2]

$$dx = \frac{Ipri \cdot Epri(\cos\theta img - \cos\theta por)}{Ipri \cdot \cos\theta por + Epri \cdot \cos\theta img}$$

Ipri: the distance from the deflecting surface of the deflecting element in the on-axis beam to the front side principal plane in the sub scanning direction;

Epri: the distance from the rear side principal plane in the sub scanning direction in the on-axis beam to the surface to be scanned;

θpor: the angle formed in the main scanning plane by the most off-axis beam deflected by the deflecting element with respect to the optical axis;

θimg: the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis;

that the sign of the curvature of at least one of the opposite lens surfaces of the single lens constituting the third optical element in the subscanning plane is reversed from the on-axis toward the off-axis; and

that the third optical element is made by plastic molding; or

that the third optical element is made by glass molding.

[0020]

[Embodiments]

Before some embodiments of the present invention are described, means for achieving the objects of the present invention will first be described. To achieve the above-described objects in the scanning optical apparatus, it is necessary to optimize the lens shape

of the fθ lens and to uniformize the lateral magnifications in the sub scanning direction on the axis and off the axis. Figure 18 is a cross-sectional view of the essential portions in the main scanning direction between the light deflector (deflecting element) of the scanning optical apparatus and the surface to be scanned. To uniformize the lateral magnifications in the sub scanning direction on the axis and off the axis, it is necessary to determine the principal plane position so that the ratios of the lengths of optical path on the axis and off the axis may be equal to each other.

[0021]

Accordingly, the principal plane position of the fθ lens in the sub scanning direction is determined so as to satisfy the following conditions:

$$Ipri : Epri = Imar : Emar$$

$$Ipri \cdot Emar = Epri \cdot Imar \quad \ldots (a)$$

where

Ipri: the distance from the deflecting surface of the light deflector to the front side principal plane in the sub scanning direction in the on-axis beam;

Epri: the distance from the rear side principal plane in the sub scanning direction to the

surface to be scanned in the on-axis beam;

Imar: the distance from the deflecting surface of the light deflector to the front side principal plane in the sub scanning direction in the most off-axis beam;

Emar: the distance from the rear side principal plane in the sub scanning direction to the surface to be scanned in the most off-axis beam.

[0022]

Generally, the off-axis beam is refracted in the direction of the optical axis in the main scanning plane in order to satisfy the fθ characteristic and therefore, a focus 71 in the main scanning plane of the principal plane in the sub scanning direction for satisfying the above expression (a) is a plane curved toward a light deflector 5 off the axis as shown in Figure 18. Here, when the curve amount on the most off-axis is dx,

$$Emar = (Epri+dx)/\cos\theta img$$

$$Imar = (Ipri-dx)/\cos\theta por$$

and consequently,

$$Ipri(Epri+dx)/\cos\theta img = Epri(Ipri-dx)/\cos\theta img$$

$$dx(Ipri\cdot\cos\theta por+Epri\cdot\cos\theta img)$$

$$= Ipri\cdot Epri(\cos\theta img-\cos\theta por)$$

[0023]

[Numerical Formula 3]

$$dx=\frac{Ipri\cdot Epri(\cos\theta img-\cos\theta por)}{Ipri\cdot \cos\theta por+Epri\cdot \cos\theta img} \quad \ldots \text{(b)}$$

where

θpor: the angle formed in the main scanning plane by the most off-axis beam deflected by the light deflector with respect to the optical axis of the fθ lens;

θimg: the angle formed in the main scanning plane by the most off-axis beam incident on the surface to be scanned with respect to the optical axis of the fθ lens.

[0024]

Accordingly, to uniformize the lateral magnification in the sub scanning direction, it is necessary to set the curve amount dx of the locus of the principal plane in the sub scanning direction to a value derived from the above expression (b).

[0025]

That is, when in an actual scanning optical apparatus, the curve amounts of the loci, in the main scanning plane, of the front side principal plane and the rear side principal plane of an fθ lens in the sub scanning direction (the difference in the direction of

the optical axis between the most off-axis principal plane position and the on-axis principal plane position) are xm and xu, respectively, it is desirable to determine the principal plane position so as to satisfy the condition that

$$xm \leq dx \leq xu. \qquad \ldots (1)$$

[0026]

If the above conditional expression (1) is departed from, irregularity will occur to the lateral magnification in the sub scanning direction and the change in spot diameter due to image height will become great, and this will pose a problem in practice.

[0027]

Next, as regards a method of changing the principal plane position in the sub scanning direction, the deflecting surface of the light deflector and the surface to be scanned are brought into optically conjugate relationship with each other in the sub scanning direction of the fθ lens as previously described to thereby effect the correction of plane inclination and therefore, the refractive power itself of the fθ lens cannot be varied.

[0028]

Accordingly, the first lens surface and the second lens surface of the fθ lens in the sub scanning

direction are bent to thereby effect the movement of the principal plane position. By the bending, the principal plane of the lens can be moved without the refractive power of the lens itself being changed and therefore, the meridian line r is continuously changed from the on-axis toward the off-axis and an optimum lens shape can be provided depending on location, whereby the lateral magnification in the sub scanning direction can be uniformized.

[0029]

By optimizing the lens shape of the fθ lens in this manner, the F number (F No.) in the sub scanning direction of the beam of light incident on the surface to be scanned can be uniformized, and the variation in the spot diameter in the sub scanning direction due to image height which has heretofore been a problem peculiar to a single-lens fθ lens can be minimized.

[0030]

Also for a beam of light emerging from a light source (light source unit) off the optical axis, the surface to be scanned can be highly accurately scanned without causing the curve of the scanning line, whereby there can be provided a scanning optical apparatus suitable also for multibeam scanning.

[0031]

Some embodiments of the present invention will now be described.

[0032]

(A) and (B) of Figure 1 are cross-sectional views of Embodiment 1 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[0033]

In these views, reference numeral 1 designates light source means (a light source unit) comprising, for example, a semiconductor laser.

[0034]

Reference numeral 2 denotes a collimator lens as a first optical element which converts a divergent beam of light emitted from the light source means 1 into a convergent beam of light. Reference numeral 3 designates an aperture stop which regularizes the diameter of the beam of light passing therethrough.

[0035]

Reference numeral 4 denotes a cylindrical lens as a second optical element which has predetermined refractive power only in the sub scanning direction and causes the beam of light passed through the aperture stop 3 to be imaged as a substantially linear image on the deflecting surface 5a of a light deflector

(deflecting element) 5 which will be described later in the sub scanning section.

[0036]

Reference numeral 5 designates a light deflector as a deflecting element which comprises, for example, a polygon mirror (rotatable polygon mirror) and is rotated at a predetermined speed in the direction of arrow A by drive means (not shown) such as a motor.

[0037]

Reference numeral 6 denotes an fθ lens (imaging optical system) as a third optical element comprising a lens having the fθ characteristic and disposed more toward the light deflector 5 side than the intermediate portion between the light deflector 5 and a photosensitive drum surface 8 as a surface to be scanned. In the present embodiment, the opposite lens surface of the fθ lens 6 both comprise a toric surface which is aspherical in the main scanning plane, and continuously varies the curvature in the sub scanning plane (a plane containing the optical axis of the third optical element and orthogonal to the main scanning plane) from the on-axis toward the off-axis in the effective portion of the lens. Thereby, in Embodiment 1, the change in F number (F No.) in the sub scanning direction due to the image height of the beam of light

incident on the surface 8 to be scanned, i.e., the change in spot diameter, is minimized. The fθ lens 6 causes the beam of light based on image information deflected and reflected by the light deflector 5 to be imaged on the photosensitive drum surface 8 and corrects the plane inclination of the deflecting surface of the light deflector 5.

[0038]

In Embodiment 1, the fθ lens 6 may be made by plastic molding or may be made by glass molding.

[0039]

In Embodiment 1, the divergent beam of light emitted from the semiconductor laser 1 is converted into a convergent beam of light by the collimator lens 2, and this beam of light (the quantity of light) is limited by the aperture stop 3 and enters the cylindrical lens 4. The beam of light having entered the cylindrical lens 4, in the main scanning section, emerges therefrom intactly in that state. Also, in the sub scanning section, it converges and is imaged as a substantially linear image (a linear image long in the main scanning direction) on the deflecting surface 5a of the light deflector 5. The beam of light deflected and reflected by the deflecting surface 5a of the light deflector 5 is directed onto the photosensitive drum

surface 8 through the fθ lens 6 having different refractive powers in the main scanning direction and the sub scanning direction, and scans the photosensitive drum surface 8 in the direction of arrow B by the light deflector 5 being rotated in the direction of arrow A. Thereby, image recording is effected.

[0040]

In Embodiment 1, the lens shape of the fθ lens in the main scanning direction is an aspherical surface shape which can be represented by a function up to the tenth-order, and the lens shape in the sub scanning direction is comprised of a spherical surface continuously varying in the direction of image height. The lens shape, when for example, the point of intersection between the fθ lens and the optical axis is the origin and the direction of the optical axis is the X-axis and the axis orthogonal to the optical axis in the main scanning plane is the Y-axis and the axis orthogonal to the optical axis in the sub scanning plane is the Z-axis, is such that the generating-line direction corresponding to the main scanning direction can be represented by the following expression:

[0041]

[Numerical Formula 4]

$$X=\frac{Y^2/R}{1+(1-(1+K)(Y/R)^2)^{1/2}}$$

$$+B_4Y^4+B_6Y^6+B_8Y^8+B_{10}Y^{10}, \quad ..(c)$$

(where R is the radius of curvature, K, B_4 , B_6, B_8 and B_{10} are aspherical surface coefficients) and the meridian-line direction corresponding to the sub scanning direction (the direction orthogonal to the main scanning direction containing the optical axis) can be represented by the following expression:

[0042]

[Numerical Formula 5]

$$S=\frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2}}, \quad ... (d)$$

(where $r' = r(1+D_2Y^2+D_4Y^4+D_6Y^6+D_8Y^8+D_{10}Y^{10})$.

[0043]

Figure 4 shows the optical arrangement in Embodiment 1 and the aspherical surface coefficients of the fθ lens 6.

Figure 7 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 6 in the lengthwise direction. As shown in Figure 5, the curvature of the meniscus shape is sharp on the axis and becomes plano-convex

from the on-axis toward the off-axis. Figure 10 is an illustration showing the aspherical surface shape of the fθ lens 6. In Figure 10, thick solid lines indicate the lens surface shapes in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0044]

In Embodiment 1, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

$dx = 6.50$

from

$Ipri = 48.73$ $Epri = 108.77$

$\theta por = 44.4°$ $\theta img = 29.10°$.

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 6 in the sub scanning direction and the curve amount xu of the locus of the rear side principal plane thereof are

$xm = 3.24$ $xu = 7.48$

and these values satisfy the aforementioned conditional expression (1) ($xm \leq dx \leq xu$).

[0045]

Thereby, in Embodiment 1, the lateral magnification in the sub scanning direction between the light deflector 5 and the surface 8 to be scanned can be uniformized on the axis and off the axis to a level free of any practical problem, and as shown in Figure B, the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0046]

(A) and (B) of Figure 2 are cross-sectional views of Embodiment 2 of the present invention in the main scanning direction and the sub scanning direction, respectively. In Figure 2, the same elements as the elements shown in Figure 1 are given the same reference numerals.

[0047]

The differences of Embodiment 2 from the aforedescribed Embodiment 1 are that the divergent beam of light emitted from the semiconductor laser (the light source unit) is converted not into a convergent beam of light but into a parallel beam of light by the collimator lens and that corresponding thereto, the lens shape of the fθ lens is made different. In the

other points, the construction and optical action of Embodiment 2 are substantially similar to those of Embodiment 1, whereby a similar effect is obtained.

[0048]

Figure 5 shows the optical arrangement in Embodiment 2 and the aspherical surface coefficients of an fθ lens 26.

Figure 8 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 26 in the lengthwise direction. As shown in Figure 8, the curvature of the meniscus shape becomes sharper from the on axis toward the off-axis. Figure 11 is an illustration showing the aspherical surface shape of the fθ lens 26. In Figure 11, thick solid lines indicate the lens surface shape in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0049]

In Embodiment 2, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

$$dx = 7.60$$

from

$Ipri = 53.94 \quad Epri = 147.51$

$\theta por = 42.0° \quad \theta img = 24.57°$.

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 26 in the sub scanning direction and the curve amount xu of the locus of the rear side principal plane thereof are

$xm = 7.34 \quad xu = 12.31$

and these values satisfy the aforementioned conditional expression (1) ($xm \le dx \le xu$).

[0050]

Thereby, in Embodiment 2, as in the aforedescribed embodiment 1, the lateral magnification in the sub scanning direction between the light deflector 25 and the surface 8 to be scanned can be uniformized on the axis and off the axis to a level free of any practical problem, and as shown in Figure 14, the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0051]

In Embodiment 2, the divergent beam of light emitted from the semiconductor laser 1 is converted into a parallel beam of light by the collimator lens 2

as previously described and therefore, the jitter by the light deflector is null, and the lens shape, in the main scanning direction, of the lens surface R2 preponderantly creating the power in the sub scanning direction is similar to the shape of the locus of the principal plane for uniformizing the lateral magnification and therefore, the lateral magnification can be uniformized even if the change of curvature in the meridian-line direction due to image height is small, whereby there can be achieved a scanning optical apparatus suitable for further highly accurate printing.

[0052]

(A) and (B) of Figure 3 are cross-sectional views of Embodiment 3 of the present invention in the main scanning direction and the sub scanning direction, respectively. In these views, the same element as the elements shown in Figure 1 are given the same reference numerals.

[0053]

The differences of Embodiment 3 from the aforedescribed Embodiment 1 are that the apparatus is comprised of a multibeam scanning optical system for scanning a plurality of beams of light emitted from a plurality of (in Embodiment 3, (two)) light source

units capable of being independently modulated, at a time, so as to have a predetermined interval therebetween on the surface to be scanned, and that correspondingly thereto, the lens shape of the fθ lens in the meridian-line direction is made different. In the other points, the construction and optical action of Embodiment 3 are substantially similar to those of the aforedescribed Embodiment 1, whereby a similar effect is obtained.

[0054]

Figure 6 shows the optical arrangement in Embodiment 3 and the aspherical surface coefficients of an fθ lens 36.

In Embodiment 3, the lens shape of at least one of the lens surfaces of the fθ lens 36 in the meridian-line direction is set so that the sign of curvature may be reversed from on the on-axis toward the off-axis. Therefore, the meridian-line direction of the fθ lens 36 corresponding to the sub scanning direction is represented by the following expression:

[0055]

[Numerical Formula 6]

$$S=\frac{Z^2/r'}{1+(1-(Z/r')^2)^{1/2}}, \quad \ldots \text{ (e)}$$

where $r' = r+d_2Y^2+d_4Y^4+d_6Y^6+d_8Y^8+d_{10}Y^{10}$. Also, the generating-line direction corresponding to the main scanning direction is represented by expression (c) as in the aforedescribed Embodiment 1.

[0056]

Figure 9 is an illustration showing a change of curvature in the sub scanning direction relative to the position of the fθ lens 36 in Embodiment 3 in the lengthwise direction. As shown in Figure 9, on the lens surface R1, the sign of curvature in the sub scanning direction is reversed from on the on-axis toward the off-axis, and the meniscus shape on the axis changes into a biconvex shape off the axis. Figure 12 is an illustration showing the aspherical surface shape of the fθ lens 36. In Figure 12, thick solid lines indicate the lens surface shape in the main scanning direction, and thin solid lines are the loci of the principal plane in the sub scanning direction, and indicate the front side principal plane and the rear side principal plane.

[0057]

In Embodiment 3, the curve amount dx of the locus of the principal plane for suppressing the change of lateral magnification in the sub scanning direction due to image height is

dx = 6.50

from

Ppri = 48.73   Epri = 108.77

θpor = 44.4°   θimg = 29.10°.

Also, the curve amount xm of the locus of the front side principal plane of the fθ lens 36 in the sub scanning direction and the curve amount xu of the locus of the rear side principal plane thereof are

xm = 4.93   xu = 9.10

and these values satisfy the aforementioned conditional expression (1) (xm≤dx≤xu).

[0058]

Thus, in Embodiment 3, as in the aforedescribed Embodiments 1 and 2, the lateral magnification in the sub scanning direction between the light deflector 5 and the surface 8 to be scanned can be uniformized to a level free of any practical problem on the axis and off the axis, and the change of the spot diameter in the sub scanning direction due to image height can be minimized. Thereby, there is achieved a scanning optical apparatus which is inexpensive and suitable for highly accurate printing.

[0059]

Also, Embodiment 3 is a multibeam scanning optical apparatus using a plurality of beams of light to scan

the surface to be scanned at a time and therefore, the curve of the scanning line provides pitch irregularity on the image and this is not good.

[0060]

So, in Embodiment 3, the radius of curvature in the sub scanning direction is continuously varied in the effective portion of the lens by image height, whereby the curve of the scanning line on the surface to be scanned can be eliminated as shown in Figure 12, and thus, there is achieved a scanning optical apparatus (multibeam scanning optical apparatus) of high image quality free of pitch irregularity.

[0061]

[Effect of the Invention]

According to the present invention, there can be achieved a compact scanning optical apparatus suitable for highly accurate printing in which when as previously described, a beam of light converted by a collimator lens is to be imaged on a surface to be scanned by an fθ lens through a light deflector, curvature of image field, distortion, etc. are well corrected by optimizing the lens shape of the fθ lens and the non-uniformity of the lateral magnification in the sub scanning direction between the light deflector and the surface to be scanned can be eliminated to

thereby suppress the change of F number in the sub scanning direction due to image height, i.e., the change of the spot diameter.

[0062]

Further, according to the present invention, there can be achieved a compact scanning optical apparatus suitable for multibeam scanning in which a beam of light from the light source unit which is off the optical axis can also be scanned highly accurately without the curve of the scanning line occurring, as described above.

[Brief Description of the Drawings]

[Figure 1]

Cross-sectional views of the essential portions of Embodiment 1 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 2]

Cross-sectional views of the essential portions of Embodiment 2 of the present invention in the main scanning direction and the sub scanning direction, respectively.

[Figure 3]

Cross-sectional views of the essential portions of Embodiment 3 of the present invention in the main

scanning direction and the sub scanning direction, respectively.

[Figure 4]

A table for illustrating the optical arrangement in Embodiment 1 of the present invention and the aspherical surface coefficients of an fθ lens.

[Figure 5]

A table for illustrating the optical arrangement in Embodiment 2 of the present invention and the aspherical surface coefficients of an fθ lens.

[Figure 6]

A table for illustrating the optical arrangement in Embodiment 3 of the present invention and the aspherical surface coefficients of an fθ lens.

[Figure 7]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 1 of the present invention.

[Figure 8]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 2 of the present invention.

[Figure 9]

An illustration showing the aspherical surface shape of an fθ lens in Embodiment 3 of the present

invention.

[Figure 10]

An illustration showing the shape of the fθ lens in Embodiment 1 of the present invention in the main scanning direction.

[Figure 11]

An illustration showing the shape of the fθ lens in Embodiment 2 of the present invention in the main scanning direction.

[Figure 12]

An illustration showing the shape of the fθ lens in the main scanning direction in Embodiment 3 of the present invention.

[Figure 13]

An illustration showing the defocus characteristic of a spot diameter in the sub scanning direction on a surface to be scanned in Embodiment 1 of the present invention.

[Figure 14]

An illustration showing the defocus characteristic of the spot diameter in the sub scanning direction on a surface to be scanned in Embodiment 2 of the present invention.

[Figure 15]

An illustration showing the curve of a scanning

line in Embodiment 3 of the present invention.

[Figure 16]

A schematic view of the essential portions of the optical system of a scanning optical apparatus according to the prior art.

[Figure 17]

Cross-sectional views of the scanning optical apparatus according to the prior art in the main scanning direction and the sub scanning direction, respectively.

[Figure 18]

A cross-sectional view of the scanning optical apparatus according to the prior art in the main scanning direction and the sub scanning direction.

[Description of Reference Numerals or Symbols]

1 ... Light source means

2 ... First optical element (collimator lens)

3 ... Aperture stop

4 ... Second optical element (cylindrical lens)

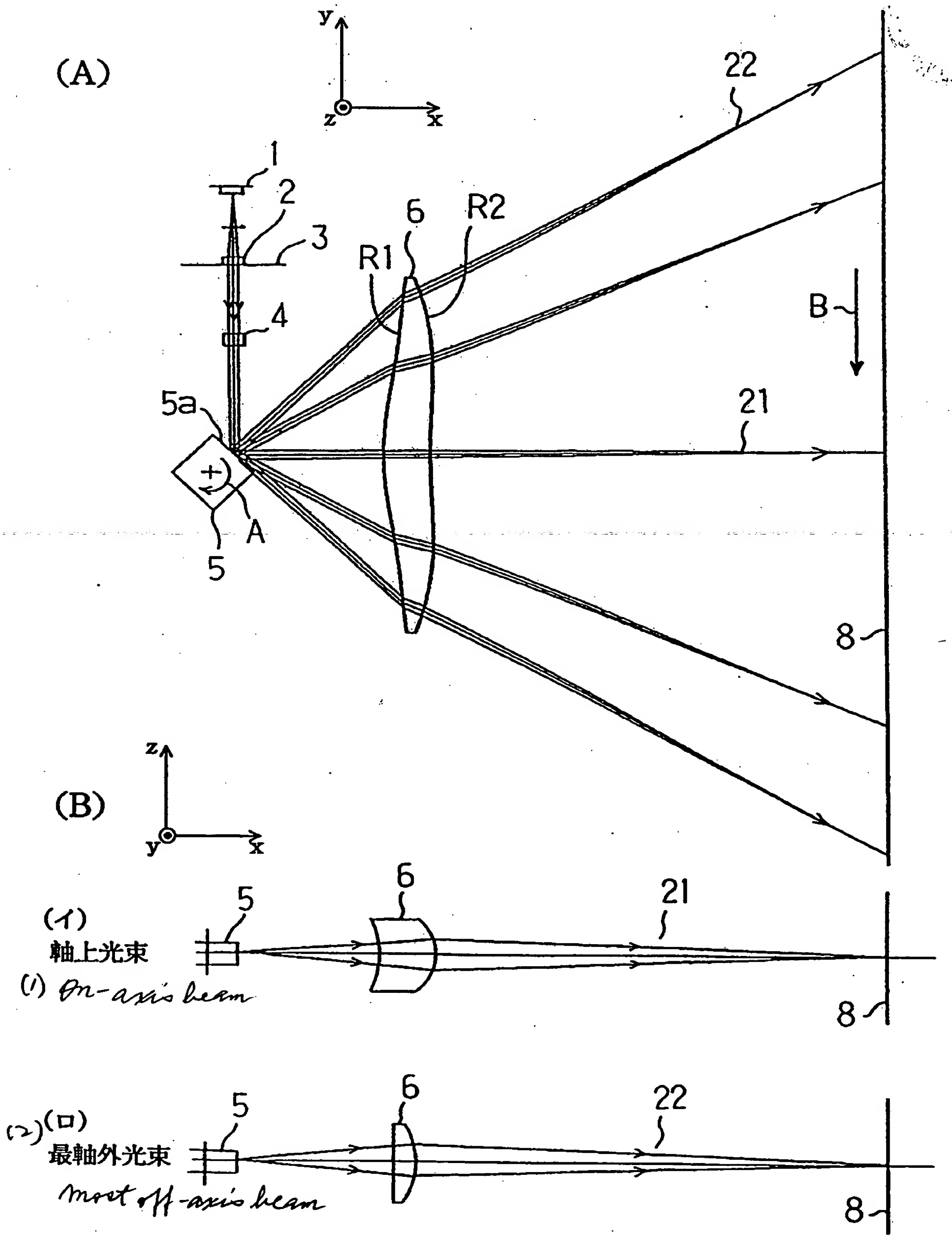
5 ... Deflecting elements (light deflectors)

6, 26, 36 ... Third optical elements (fθ lenses)

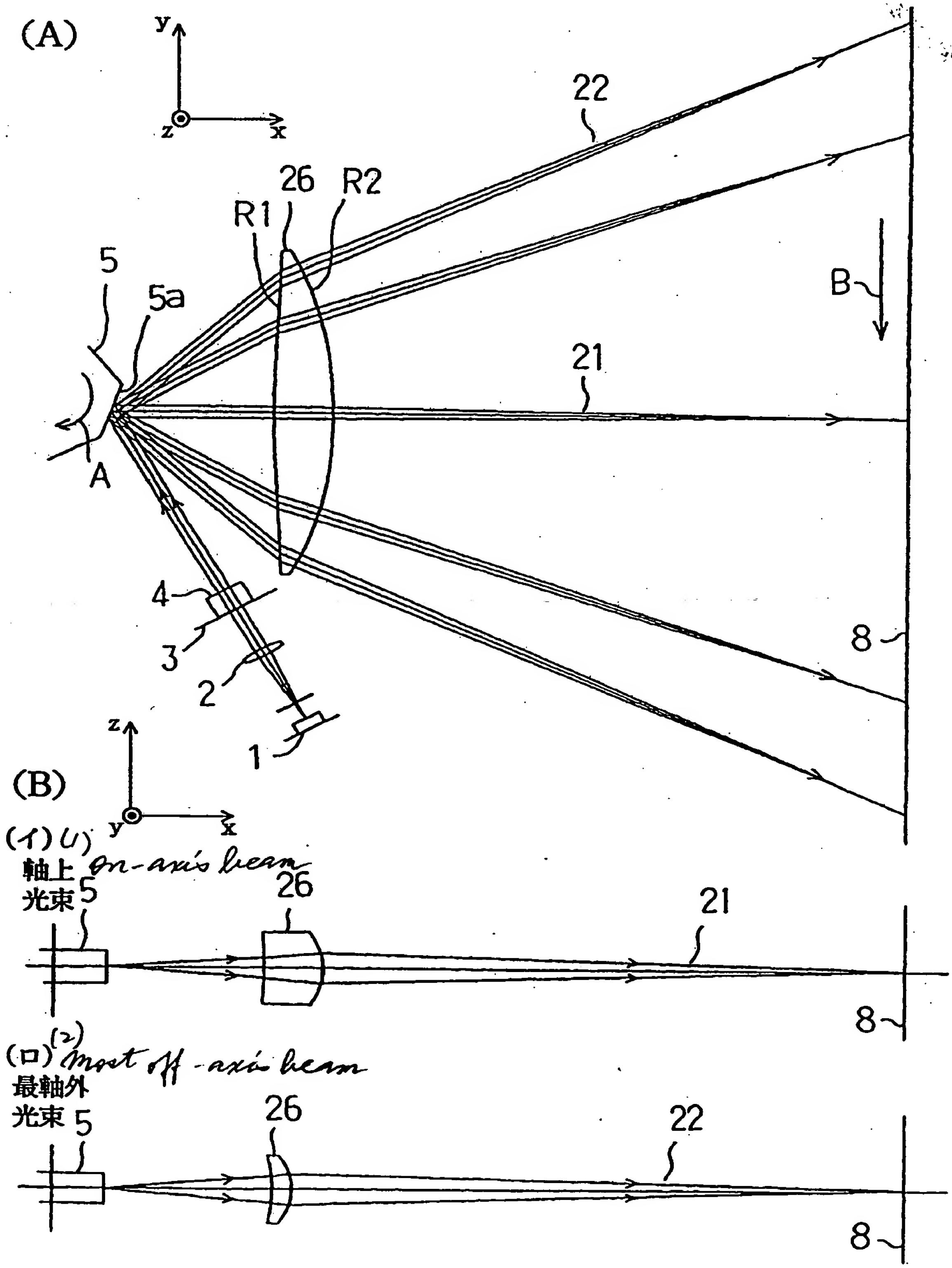
8 ... Surface to be scanned (photosensitive drum)

【書類名】　図面　[Name of the Document] Drawings

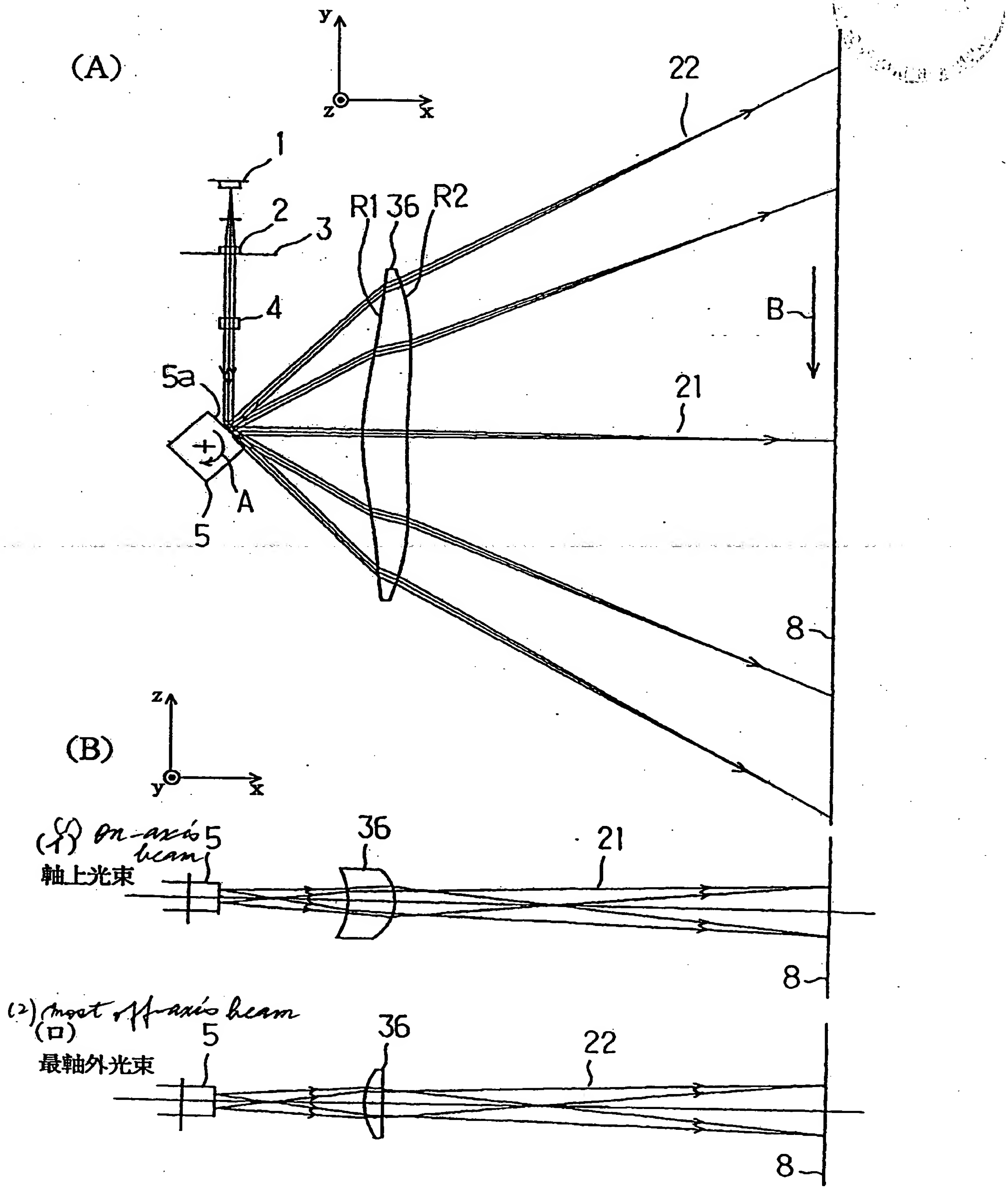
【図１】 Fig. 1



【図２】 Fig.2


(A)
y
z
x
22
26
R2
R1
5
5a
B
21
A
4
3
2
1
8
(B)
z
y
x
(イ) (1)
軸上 On-axis beam
光束
5
26
21
8
(ロ) (2) Most off-axis beam
最軸外
光束
5
26
22
8

【図３】 Fig.3


(A)
y
z
x
1
2
3
4
5a
5
A
R1
36
R2
22
21
B
8
(B)
z
y
x
(1) on-axis beam
(イ)
軸上光束
5
36
21
8
(2) most off-axis beam
(ロ)
最軸外光束
5
36
22
8

【図４】 Fig. 4

					Shape of fθ lens fθレンズ形状	
Wavelength used	使用波長	λ (nm)	780		第1面 First surface	第2面 second surface
Refractive index of fθ lens	fθレンズ屈折率	n	1.519	R	6.7814E+01	1.6154E+02
Angle of incident on polygon	ポリゴン入射角	θI	-90	K	-1.6787E+01	-1.0814E+02
Maximum angle of emergence from polygon	ポリゴン最大出射角	θ max	45	B4	-9.8604E-07	-2.2909E-06
Polygon-fθ lens	ポリゴン-fθレンズ	e	36	B6	1.5479E-11	7.1426E-10
Center thickness of fθ lens	fθレンズ中心厚	d	11	B8	8.7055E-14	-3.2030E-13
fθ lens-surface to be scanned	fθレンズ-被走査面	Sk	110.5	B10	-4.7942E-18	7.9836E-17
Maximum effective diameter of fθ lens	fθレンズ最大有効径	Ymax	42	r	-2.7332E+01	-1.1859E+01
Focal length of fθ lens	fθレンズ焦点距離	ft	213.7	D2S	1.2604E-03	4.9796E-04
Degree of convergence of collimator	コリメーター収束度			D4S	1.2255E-06	-2.0734E-07
Polygon-natural converging point	ポリゴン-自然収束点	fc	317.3	D6S	8.4502E-10	2.3479E-10
				D8S	-6.3449E-13	-1.0939E-13
				D10S	1.3148E-15	1.5644E-17
				D2E	9.3936E-04	4.4938E-04
				D4E	2.0207E-06	-4.6627E-08
				D6E	7.0546E-10	1.1322E-10
				D8E	-1.2936E-12	-5.8704E-14
				D10E	2.3372E-15	4.3944E-18

【図５】 Fig5

Shape of fθ lens

					fθレンズ形状	
					第１面 First surface	第２面 Second surface
Wavelength used	使用波長	λ(nm)	780			
Refractive index of fθ lens	fθレンズ屈折率	n	1.519	R	2.2000E+02	-1.1768E+02
Angle of incidence on polygon	ポリゴン入射角	θi	-60	K	0.0000E+00	0.0000E+00
maximum angle of emergence from polygon	ポリゴン最大出射角	θmax	42	B4	-1.1899E-06	-5.2353E-07
Polygon-fθ lens	ポリゴン-fθレンズ	e	40	B6	3.1847E-10	-8.6171E-11
Inter thickness of fθ lens	fθレンズ中心厚	d	15	B8	-2.9372E-14	1.8432E-14
fθ lens-surface to be scanned	fθレンズ-被走査面	Sk	146.45	B10	3.2427E-19	8.4808E-18
maximum effective diameter of fθ lens	fθレンズ最大有効径	Ymax	43	r	-1.1312E+02	-1.7832E+01
Focal length of fθ lens	fθレンズ焦点距離	ft	150	d2S	-4.8301E-04	4.5963E-05
				d4S	1.8211E-07	-7.1210E-08
				d6S	-1.0230E-10	1.7390E-11
				d8S	7.2371E-14	-4.3029E-15
				d10S	-2.1962E-17	-1.4545E-19
				d2E	-7.0160E-04	1.1994E-05
				d4E	3.6411E-07	-5.9970E-08
				d6E	-1.0351E-11	-1.7699E-12
				d8E	-7.6585E-14	2.1846E-14
				d10E	2.0350E-17	-9.2552E-18

【図６】 Fig. 6

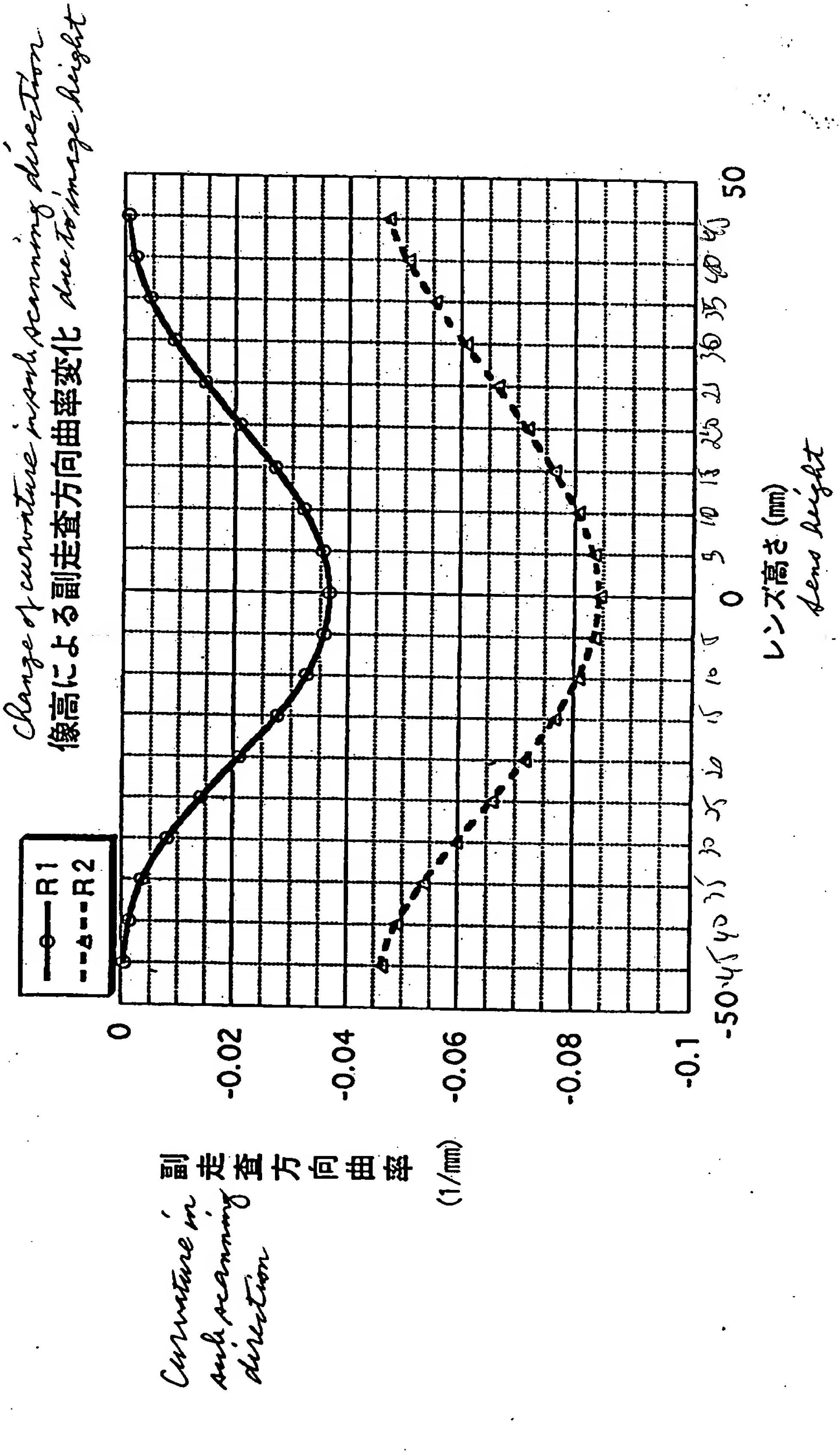
Shape of fθ lens

First surface — 第１面; Second surface — 第２面

Wavelength used
Refractive index of fθ lens
Angle of incidence on polygon
Maximum angle of emergence from polygon
Polygon - fθ lens
Center thickness of fθ lens
fθ lens - surface to be scanned
Maximum effective diameter of fθ lens
Focal length of fθ lens
Degree of convergence of collimator
Polygon - natural converging point

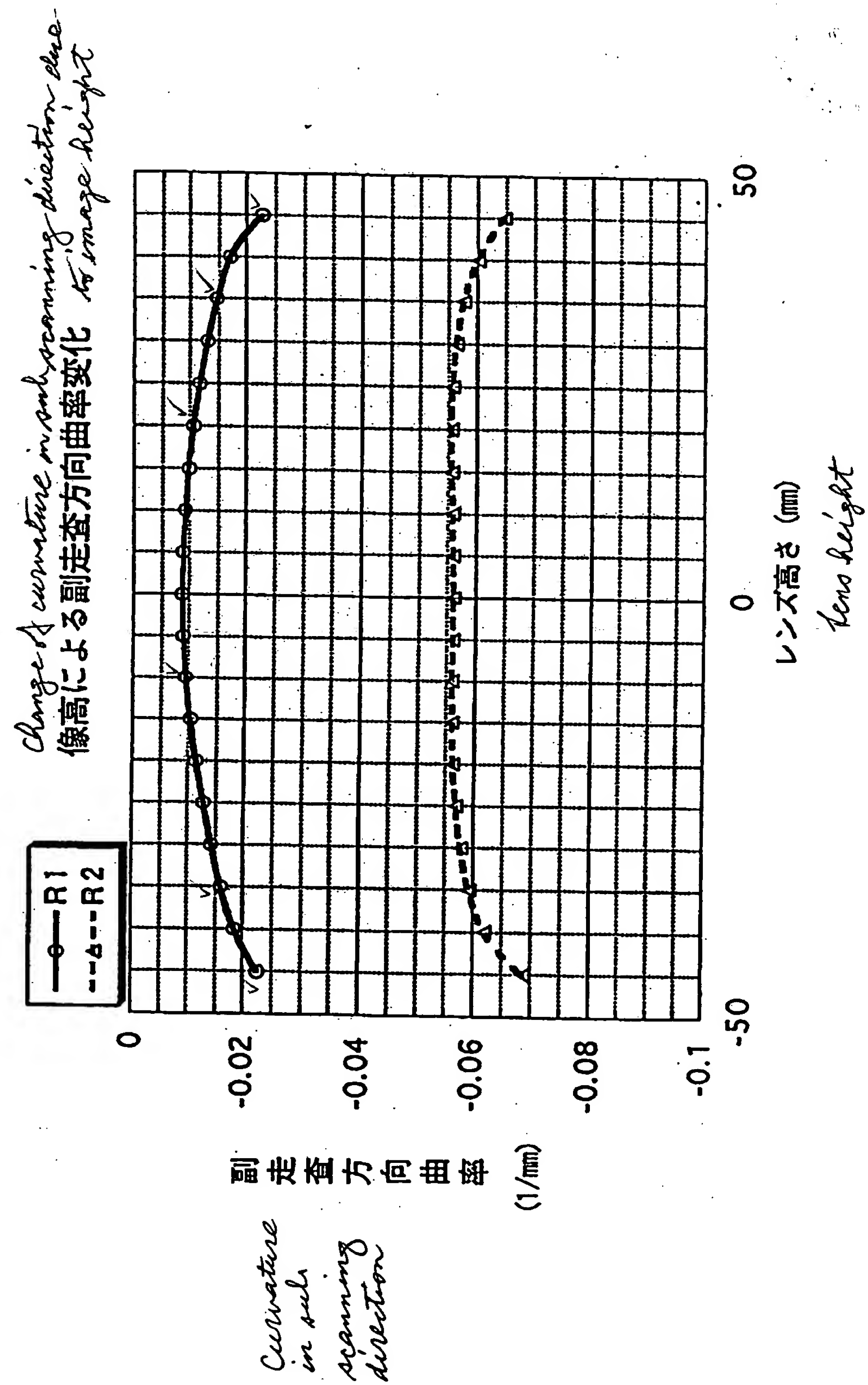
			fθレンズ形状		
使用波長	λ(nm)	780		第１面	第２面
fθレンズ屈折率	n	1.519	R	6.7814E+01	1.6154E+02
ポリゴン入射角	θi	-90	K	-1.6787E+01	-1.0814E+02
ポリゴン最大出射角	θmax	45	B4	-9.8604E-07	-2.2909E-06
ポリゴン-fθレンズ	e	36	B6	1.5479E-11	7.1426E-10
fθレンズ中心厚	d	11	B8	8.7055E-14	-3.2030E-13
fθレンズ-被走査面	Sk	110.5	B10	-4.7942E-18	7.9836E-17
fθレンズ最大有効径	Ymax	42	r	-2.8363E+01	-1.1966E+01
fθレンズ焦点距離	ft	213.7	d2S	5.4992E-05	4.4462E-05
コリメーター収束度			d4S	-2.2581E-08	-2.7866E-08
ポリゴン-自然収束点	fc	317.3	d6S	9.5892E-12	2.5295E-11
			d8S	-1.9648E-15	-1.0163E-14
			d10S	2.7992E-19	1.9816E-18
			d2E	4.3102E-05	3.9194E-05
			d4E	1.7579E-08	-1.2704E-08
			d6E	-3.6419E-11	1.1605E-11
			d8E	2.1285E-14	-3.3827E-15
			d10E	-4.6427E-18	8.2100E-20

【図７】 Fig. 7

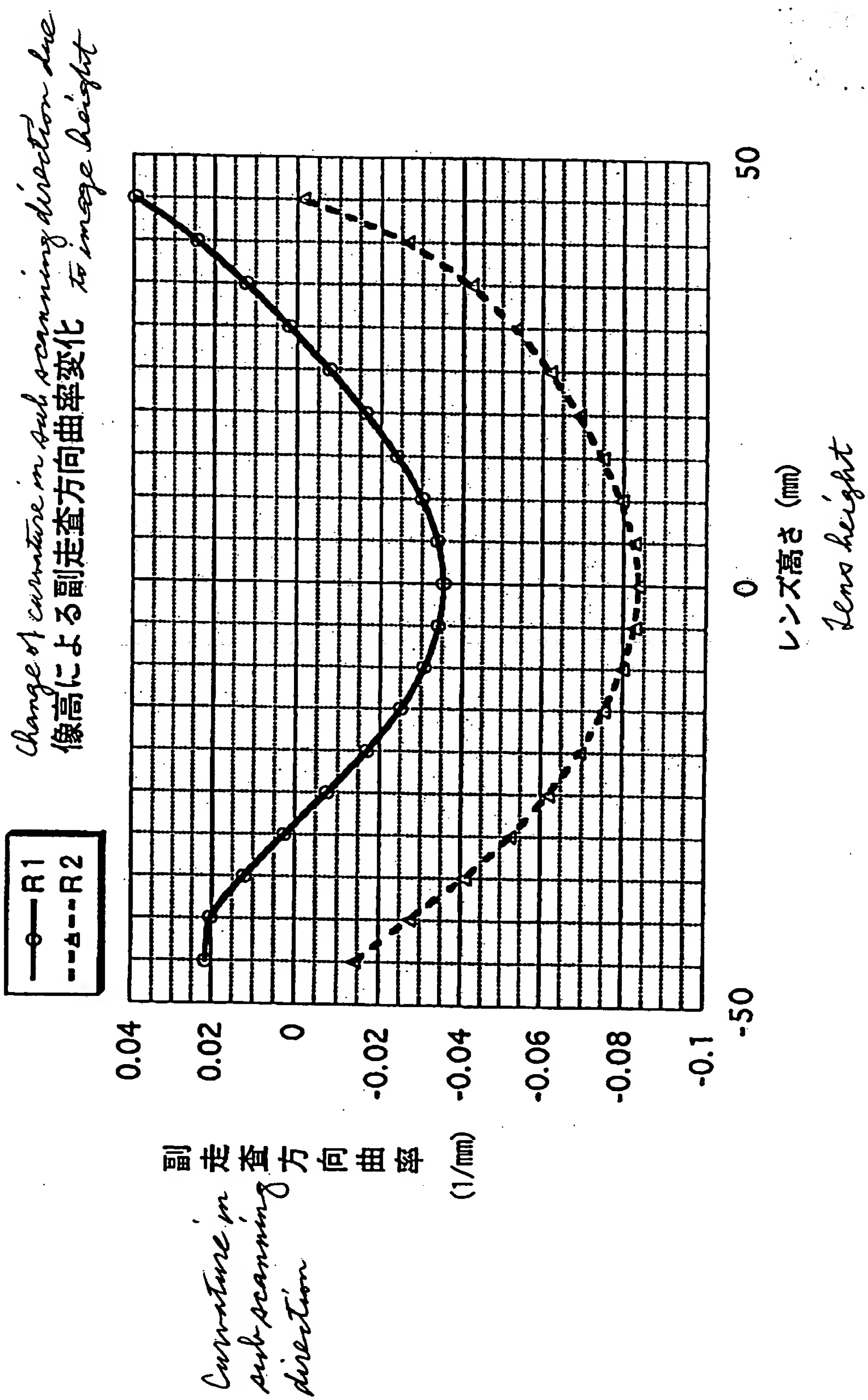


Change of curvature in sub scanning direction due to image height
像高による副走査方向曲率変化
R1
R2
0
-0.02
-0.04
-0.06
-0.08
-0.1
-50
0
50
レンズ高さ (mm)
Lens height
副走査方向曲率
(1/mm)
Curvature in sub scanning direction

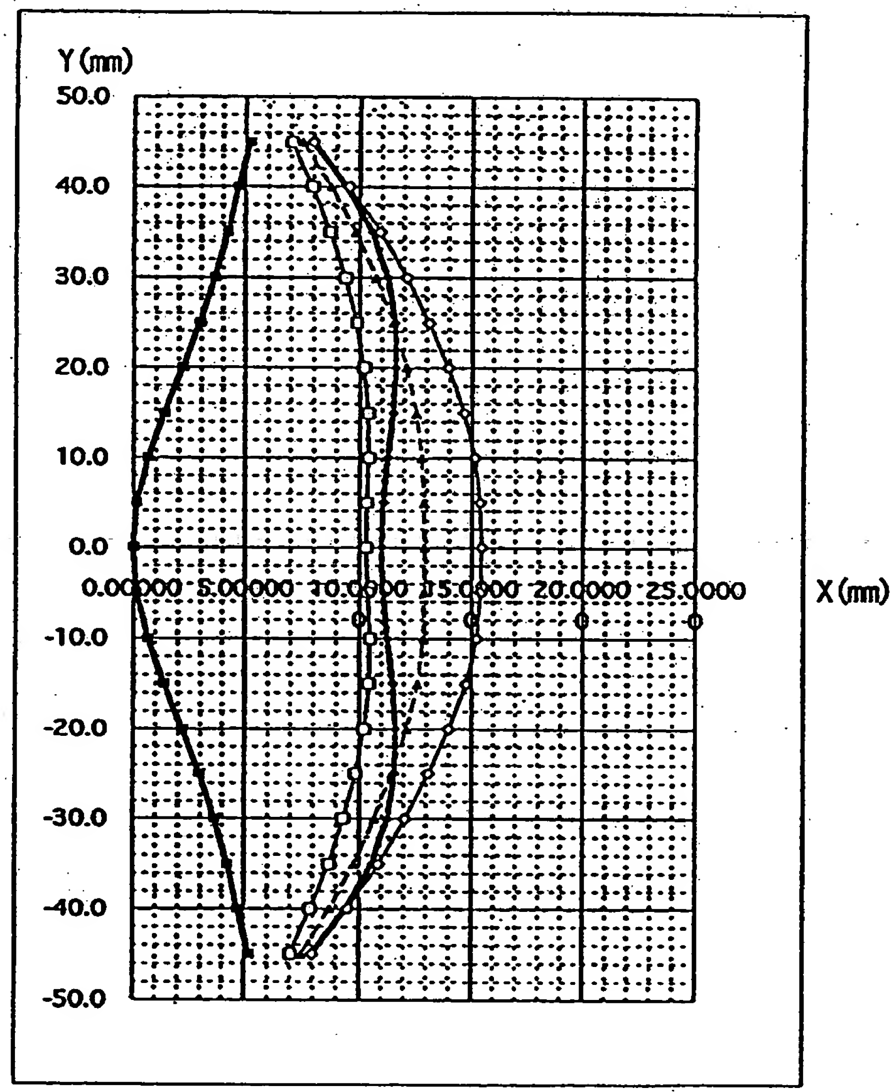
【図８】 Fig. 8


Change of curvature in sub scanning direction due to image height
像高による副走査方向曲率変化
R1
R2
0
-0.02
-0.04
-0.06
-0.08
-0.1
-50
0
50
副走査方向曲率 (1/mm)
Curvature in sub scanning direction
レンズ高さ (mm)
lens height

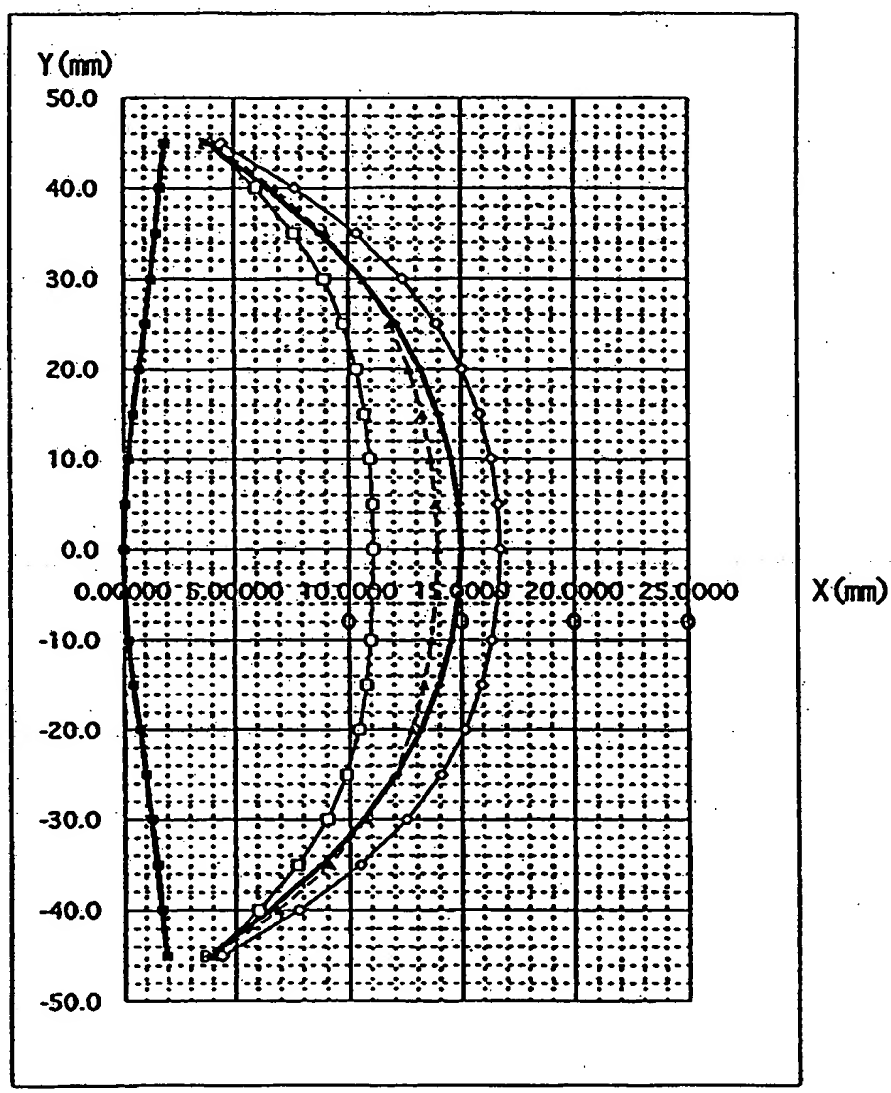
【図９】 Fig. 9


Change of curvature in sub scanning direction due to image height
像高による副走査方向曲率変化
R1
R2
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-50
0
50
レンズ高さ (mm)
Lens height
副走査方向曲率 (1/mm)
Curvature in sub-scanning direction

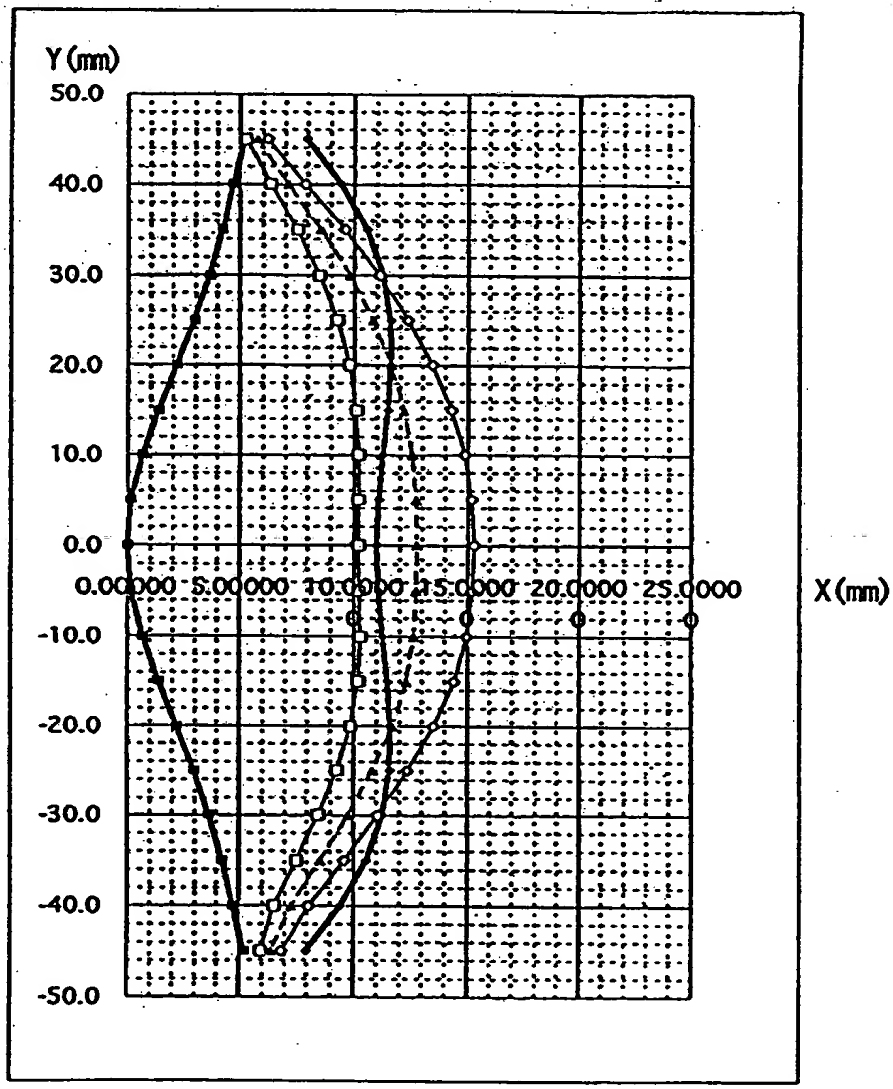
【図１０】 Fig. 10


Y(mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X(mm)

【図１１】 Fig. 11


Y (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X (mm)

【図１２】 Fig. 12

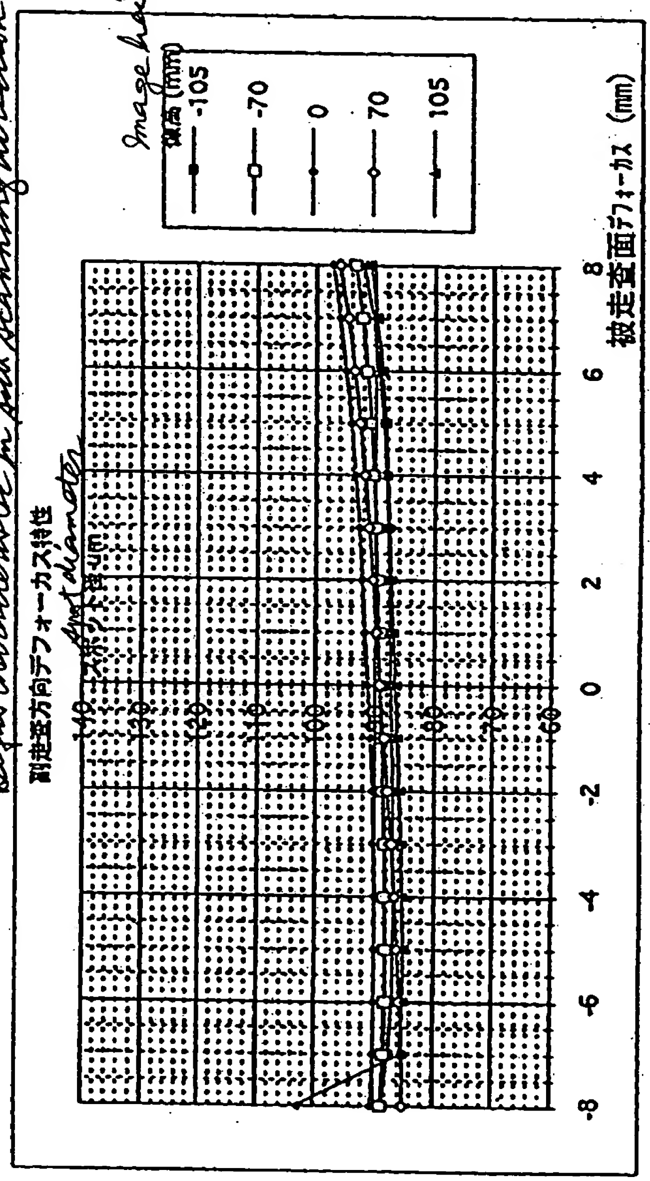

Y (mm)
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
0.00000
5.00000
10.0000
15.0000
20.0000
25.0000
X (mm)

【図１３】 Fig. 13

Defocus characteristic in sub scanning direction

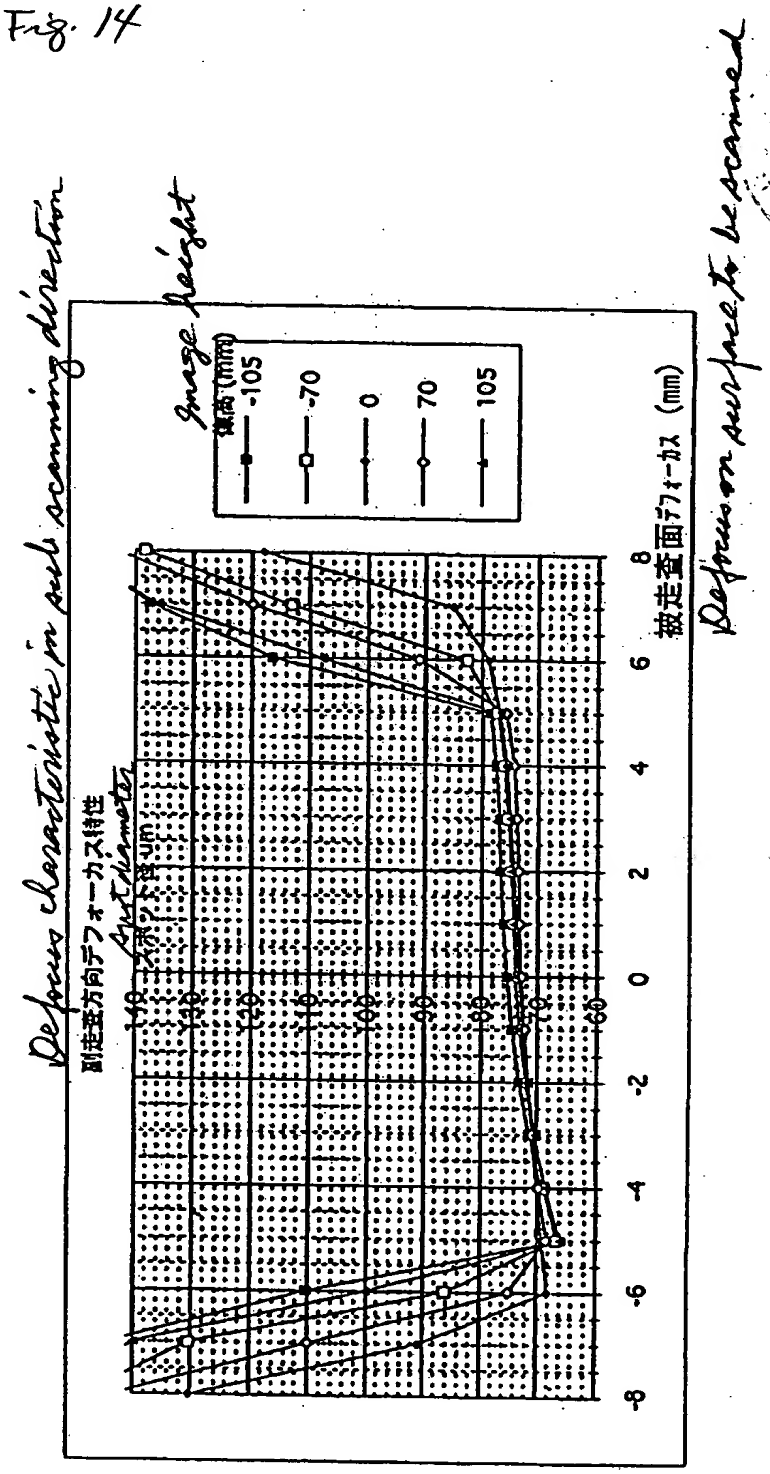
spot diameter

Image height



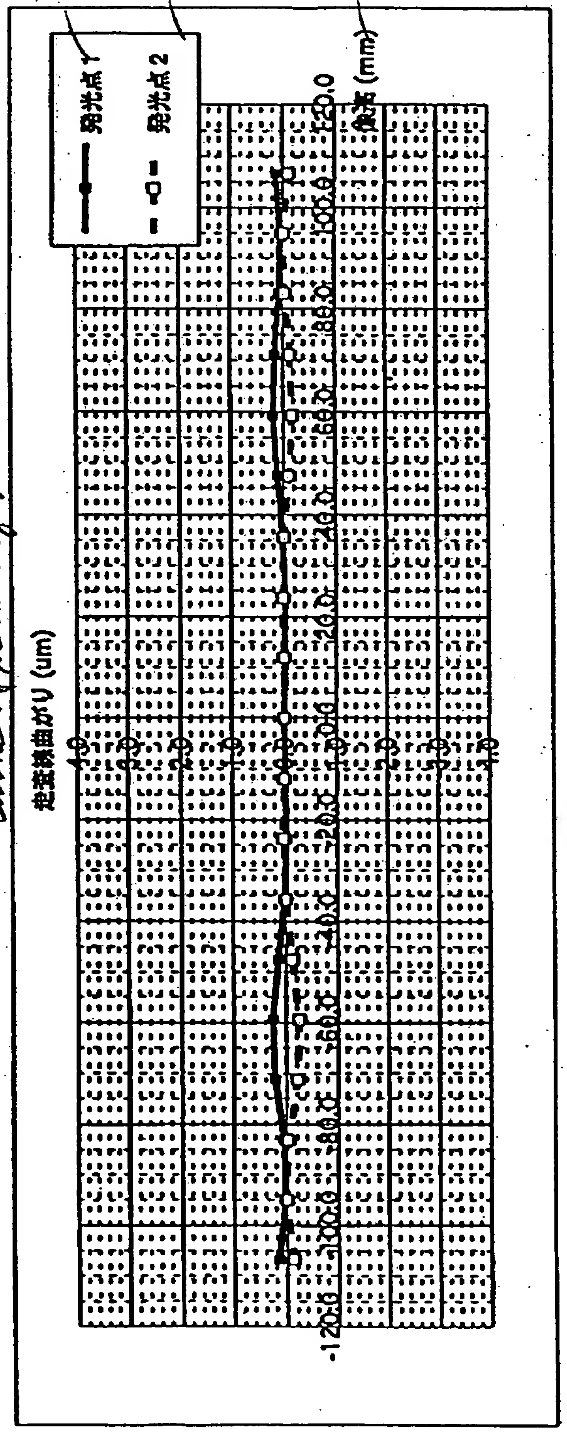
Defocus on surface to be scanned

【図１４】 Fig. 14


Defocus characteristic in sub scanning direction
副走査方向デフォーカス特性
Spot diameter
スポット径 um
Image height
像高 (mm)
-105
-70
0
70
105
140
130
120
110
100
90
80
70
60
-8
-6
-4
-2
0
2
4
6
8
被走査面デフォーカス (mm)
Defocus on surface to be scanned

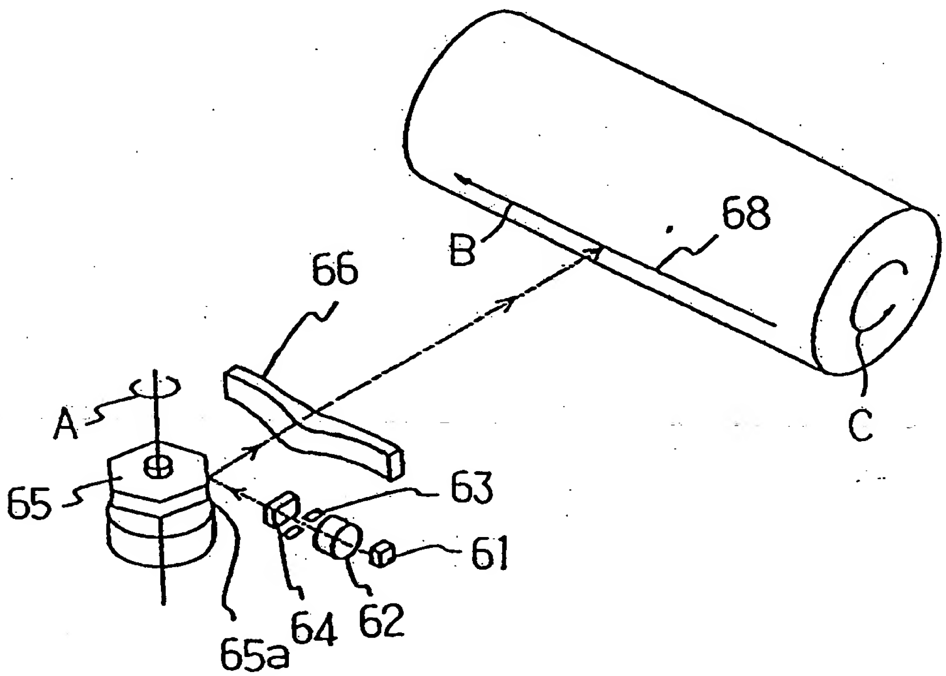
【図１５】
Fig. 15

light emitting point 1
light emitting point 2
Image height

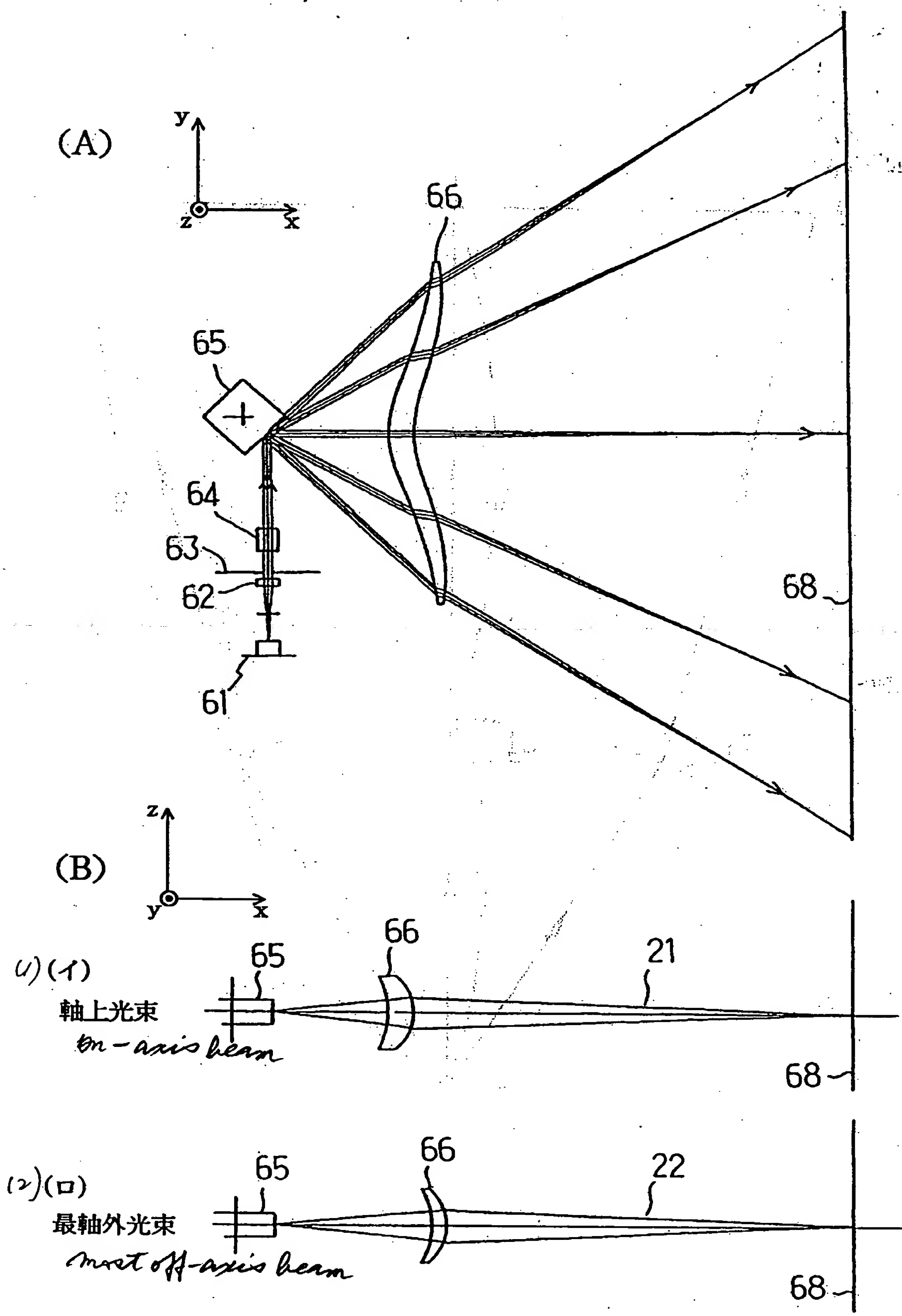


Curve of scanning line

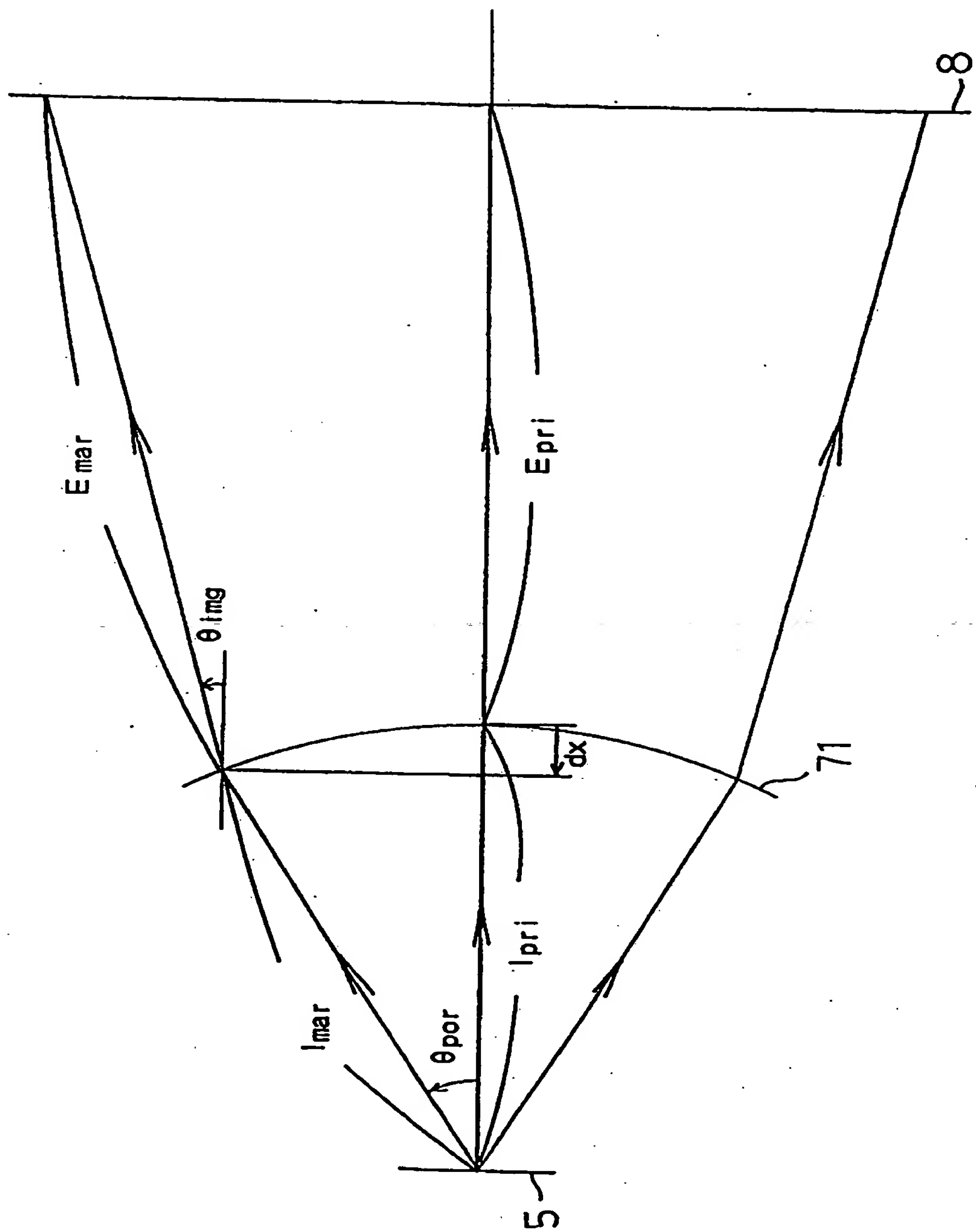
【図１６】 Fig.16



【図17】 Fig. 17


(A)
y
z
x
66
65
64
63
62
61
68
(B)
z
y
x
(1)(イ)
軸上光束
On-axis beam
65
66
21
68
(2)(ロ)
最軸外光束
most off-axis beam
65
66
22
68

【図１８】 Fig. 18



[Name of the Document] Abstract

[Abstract]

[Object] An object of the present invention is to obtain a compact scanning optical apparatus suitable for highly accurate printing by setting the shape of a single fθ appropriately.

[Constitution] According to the present invention, in a scanning optical apparatus in which a beam of light emitted from a light source means is imaged into a linear shape long in the main scanning direction on a deflecting surface of a deflecting element through a first optical element and a second optical element and the beam of light deflected by the deflecting element is imaged into a spot-like shape on a surface to be scanned through a third optical element so as to scan the surface to be scanned, the third optical element comprises a single lens, the both lens surfaces of the single lens comprise a toric surface of an aspherical shape in the main scanning plane, and the curvature of the lens surfaces of the single lens in the sub scanning plane is continuously varied from the on-axis toward the off-axis in an effective portion of the lens, thereby suppressing a change of the F number in the sub scanning direction due to the image height of the beam of light incident on the surface to be

scanned.

[Elected Drawing] Figure 1